



RADIATION BIOLOGY

EDUCATOR GUIDE

An Interdisciplinary Guide on Radiation Biology
for grades 9 through 12

Introduction and Module 1: Radiation

Revision 3
October 11, 2006

RADIATION BIOLOGY EDUCATOR GUIDE

Introduction and Module 1: Radiation

Authored by:

Jon Rask¹

Carol Elland²

Wenonah Vercoutere³

Edited by:

Esther Hill²

Sandy Dueck²

Graphic Design by:

Yael Kovo²

Julie Fletcher²

Give us your feedback:

To provide feedback on the
modules on-line, visit:

<http://radiationbiology.arc.nasa.gov/>

Module 1 Contents:

Introduction	iii
The Scenario	v
Module 1: Radiation	1
What is Radiation?	1
Where Does Radiation Come From?	2
What Are Different Kinds of Radiation?	2
Why Is Ionizing Radiation More Dangerous than Non-ionizing Radiation?	3
What is Galactic Cosmic Radiation?	3
Are We Protected from Space Radiation on Earth?	4
What Factors Determine the Amount of Radiation Astronauts Receive?	5
Does space Weather Affect Astronauts?	5
How is Radiation Measured?	6
Are There Radiation Exposure Limits?	7
How Does the Radiation Environment on Earth Compare to the Radiation Environment on the Moon and Mars?	9
Suggested Activity Ia: Modeling Waves in the Electromagnetic Spectrum	11
Suggested Activity Ib: The Cloud Chamber	13
Suggested Activity Ic: Radiation Exposure on Earth	16
Appendix 1: Additional Websites	19
Appendix 2: National Education Standards Module 1 ..	20

¹Enterprise Advisory Services Inc. (EASI),
NASA Ames Research Center, Moffett Field, CA

²Lockheed Martin, NASA Ames
Research Center, Moffett Field, CA

³Life Sciences Division, NASA Ames
Research Center, Moffett Field, CA



Introduction



Radiation biology is an interdisciplinary science that examines the biological effects of radiation on living systems. To fully understand the relationship between the two, researchers incorporate fundamentals of biology, physics, astrophysics, planetary science and engineering to solve problems in this field. This *Radiation Biology Educator Guide* helps to link these disciplines by providing background, discussion questions, objectives, research questions, and inquiry-based activities to introduce radiation biology into your high school science classroom. The suggested activities are hands-on investigations that encourage the use of science, technology, engineering, mathematics, problem-solving and inquiry skills. The activities should be considered as a general framework that can be modified based on student needs and classroom resources. This guide is aligned with the National Science Education Standards of *Science as Inquiry*, *Physical Science*, and *Life Science*, and has been organized into the following four modules:

- Module 1: Radiation
- Module 2: Radiation Damage in Living Organisms
- Module 3: Radiation Countermeasures
- Module 4: Applications to Life on Earth

The major goal of NASA's Space Radiation Project is to enable the human exploration of space without exceeding an acceptable level of risk from exposure to space radiation (for more information, see http://hacd.jsc.nasa.gov/projects/space_radiation.cfm). Space radiation is distinct from common terrestrial forms of radiation because it is comprised of high-energy protons and heavy ions that produce damage during interactions with shielding and tissue. An important safety concern for long-term space travel is the health effects from space radiation. Possible health risks include cancer, cataracts, risk of acute radiation sickness, hereditary effects, and damage to the central nervous system. Because there is limited human epidemiological data for space radiation, risk estimation must be derived through theoretical calculations and biological experimentation. NASA has been developing ground-based research facilities to simulate the space radiation environment and to analyze biological effects at the molecular cellular, and tissue level. Research performed at these facilities will help us to understand and mitigate the biological effects of space radiation on astronauts, to ensure proper calibration of the doses received by astronauts on the International Space Station (ISS), and to develop advanced material concepts for improved radiation shielding for future long-duration space exploration on the Moon and possibly on Mars.

For over 35 years, NASA has been collecting and monitoring the radiation doses received by all NASA astronauts who have traveled into space as part of the Gemini, Apollo,

Skylab, Space Shuttle, Mir and ISS programs (for more information, see <http://srag-nt.jsc.nasa.gov/>). While data on the amount of space radiation and its composition are now more readily available and well understood, the biological effects of that radiation are poorly understood. Uncertainties in predicting the nature and magnitude of space radiation biological risks still remain.⁴

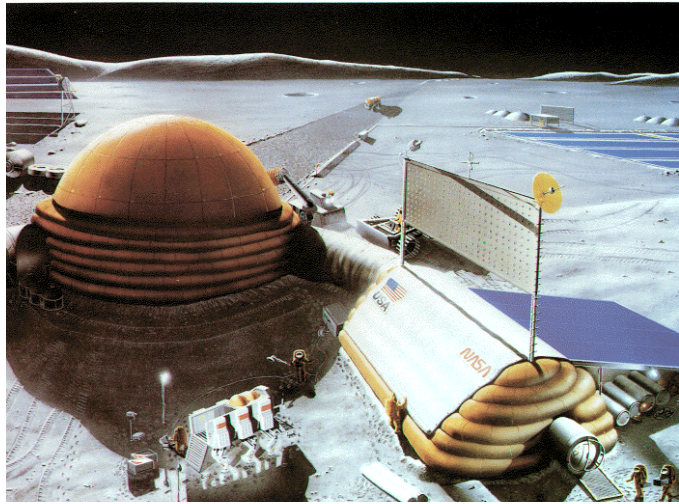
⁴ Lancet Oncol 2006; 7:431-35

.....

THE SCENARIO: Development of a Human-Tended Lunar Outpost

.....

This guide is designed to provide you with information that will be helpful in understanding why radiation biology is a crucial component in the research, development and planning for long-duration human space exploration. To help inspire students in your classroom, we suggest that you provide your students with a scenario that encompasses the radiation biology problems involved with human space exploration of the Moon, including the development of a permanently human-tended



An artist's conception of a future Moon base.

lunar outpost, as seen in the image above⁵. If such an outpost is to be safely constructed and occupied by people from Earth, we must have a complete understanding of how the biological limitations of the human body in the space environment will affect its overall design and operation. To successfully grasp the importance of radiation biology, your students will need a solid understanding of why the radiation encountered in long-duration space exploration is such an enormous challenge to the human body.

A Brief History of Humans on the Moon

It is important to note that the NASA Apollo program was designed to land humans on the Moon and bring them safely back to Earth; it was not designed to establish a permanent presence on the Moon. The duration of the lunar surface missions were very short, largely due to the risks of space radiation exposure and the unpredictable nature of the solar weather.⁶

Between 1969 and 1972, six of the seven lunar landing missions that included Apollos 11, 12, 14, 15, 16 and 17 were successful and enabled 12 astronauts to walk on the Moon. While on the surface, the astronauts carried out a variety of lunar surface experiments designed to study lunar soil mechanics, meteoroids, seismic activity, heat flow, lunar ranging, magnetic fields and solar wind. The astronauts also gathered samples and

⁵ <http://vesuvius.jsc.nasa.gov/er/seh/gotomoon.gif>

⁶ http://www.space.com/scienceastronomy/mars_dangers_040120.html

returned to Earth with over 600 pounds of Moon rocks and dust. Since 1972, no human has returned to the Moon.

The table below shows the amount of time astronauts spent on the surface of the Moon during each lunar landing and the average radiation dose.

Mission	Total Duration	Lunar Surface Duration	Average Radiation Dose⁷
Apollo 11	08 days, 03 hrs, 13 mins	21 hrs, 38 mins	0.18 rad
Apollo 12	10 days, 4 hrs, 31 mins	31 hrs, 31 mins	0.58 rad
Apollo 14	09 days, 01 min	33 hrs 31 mins	1.14 rad
Apollo 15	10 days, 01 hr, 11 mins	66 hrs, 54 mins	0.30 rad
Apollo 16	11 days, 01 hr 51 mins	71 hrs, 2 mins	0.51 rad
Apollo 17	12 days, 13 hrs, 51 mins	74 hrs, 59 mins	0.55 rad

Through these and robotic missions including the three Russian Luna sample return missions,⁸ NASA Lunar Prospector, and the upcoming Lunar Precursor and Robotic Program, scientists have and will continue to learn a great deal about how and when the Moon was formed, how it may have played an important role in the origin of life here on Earth, and the environment, including radiation, on and below the Moon's surface.

Future Lunar Colonization

Ask your students questions intended to prompt them into thinking about what biological requirements must be met for successful long-term human exploration of the Moon. Consider what limitations the human body presents in such an endeavor. Start by asking: "If you had to prepare for future lunar colonization, what would you have to know and need to accomplish this task safely?" To establish a permanently inhabited lunar outpost, your team will need to understand how the space radiation environment affects living systems.

Exploring the surrounding lunar landscape (image at right⁹) and traveling to remote locations on the Moon may also be part of the activities lunar explorers will perform. Remind your students that there are unknowns about the proposed long-duration exploration of the Moon. Students will



An Apollo astronaut explores the lunar surface.

⁷ <http://lsda.jsc.nasa.gov/books/apollo/Resize-jpg/ts2c3-2.jpg>

⁸ http://www.russianspaceweb.com/spacecraft_planetary_lunar.html

⁹ http://science.nasa.gov/headlines/y2005/24may_lola.htm

need to understand the hazards of solar and cosmic radiation, their impact on materials and the human body, the radiation environment on the surface of the Moon, and the amount of radiation astronauts can be exposed to.

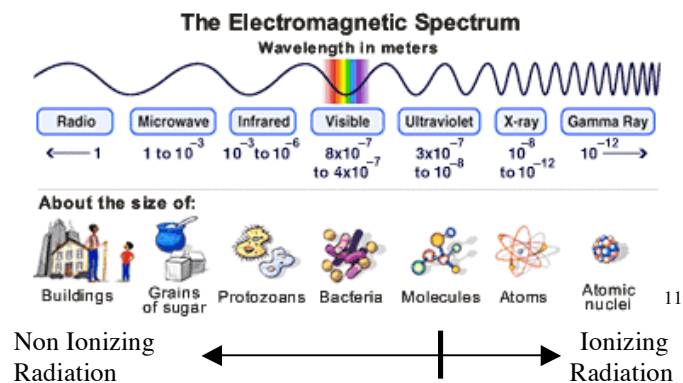
Another important concept for students to understand is space weather. Space weather refers to the conditions and processes occurring in space that have the potential to affect spacecraft or people in the space environment. Space weather processes include changes in the interplanetary magnetic field, coronal mass ejections, disturbances in Earth's magnetic field, and changes in the solar wind (energy that flows from the Sun in the form of particles like protons or electromagnetic radiation). Help is needed in deciding which materials should be used for the spacesuits, spacecraft and habitation units on the Moons. To provide useful planning and launch date recommendations, students will also need to understand how the Sun's activity affects the radiation environment in the solar system.

Module 1: Radiation

What is Radiation?

Radiation is a form of energy that is emitted or transmitted in the form of rays, electromagnetic waves and/or particles. In some cases, radiation can be seen (visible light) or felt (infrared radiation), while other forms like X-rays and gamma rays are not visible and can only be observed directly or indirectly with special equipment. Although radiation can have negative effects both on biological and mechanical systems, it can also be carefully used to learn more about each of those systems.

The motion of electrically charged particles produces electromagnetic waves. These waves are also called "electromagnetic radiation" because they radiate from the electrically charged particles. They travel through empty space as well as through air and other substances. Scientists have observed that electromagnetic radiation has a dual "personality." Besides acting like waves, it acts like a stream of particles (called photons) that has no mass. The photons with the highest energy correspond to the shortest wavelengths and vice versa. The full range of wavelengths (and photon energies) is called the electromagnetic spectrum¹⁰. The shorter the wavelength, the more energetic the radiation and the greater the potential for biological harm.



On Earth we are protected from much of the electromagnetic radiation that comes from space by Earth's atmosphere and magnetic field. Most radiation is unable to reach the surface of the Earth except at limited wavelengths, such as the visible spectrum, radio waves, frequencies and some ultraviolet wavelengths, and some high-energy ionizing radiation. As we rise through the atmosphere, climb a high mountain, take a plane flight, or go to the ISS or to the Moon, we rapidly lose the protection of the atmosphere and

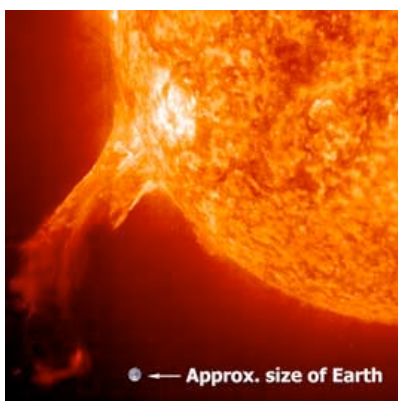
¹⁰ <http://www.lbl.gov/MicroWorlds/ALSTool/EMSpec/>

¹¹ <http://imagers.gsfc.nasa.gov/ems/waves3.html>

magnetic field. To better understand how electromagnetic waves behave, have the students perform *Activity Ia, Modeling Waves in the Electromagnetic Spectrum*.

Where Does Radiation Come From?

In our daily life we are exposed to electromagnetic radiation through the use of microwaves, cell phones, and diagnostic medical applications such as X-rays. In addition to human-created technologies that emit electromagnetic radiation such as radio transmitters, light bulbs, heaters and gamma ray sterilizers (tools that kill microbes in fresh or packaged food), there are many naturally occurring sources of electromagnetic and ionizing radiation. These include radioactive elements in the Earth's crust, radiation trapped in Earth's magnetic field, stars and other astrophysical objects like quasars or galactic centers.



Earth's biggest source of radiation is the Sun. The Sun emits all wavelengths in the electromagnetic spectrum. The majority are in the form of visible, infrared and ultraviolet radiation (UV). Occasionally, giant explosions called solar flares and Coronal Mass Ejections (CME) occur on the surface of the Sun and release massive amounts of energy out into space in the form of X-rays, gamma rays, and streams of protons and electrons called solar particle events (SPE).¹² In the left image¹³ a robotic spacecraft called the Solar and Heliospheric Observatory (SOHO) captured an erupting CME from the surface of

the Sun. Note the Earth inset at the approximate scale of the image. These CME can have serious consequences on astronauts and their equipment, even at locations that are far from the Sun.

What Are the Different Kinds of Radiation?

Ionizing radiation is composed of either particles or photons that have enough energy to ionize an atom or molecule as it passes through a material. Radiation can be either non-ionizing (low energy) or ionizing (high energy) radiation. Ionizing is either particles or photons that have enough energy to ionize an atom or molecule by completely removing an electron from its orbit, thus creating a more positively charged atom. Less energetic non-ionizing radiation does not have enough energy to remove electrons from the material it traverses. Examples of ionizing radiation include alpha particles (a helium atom nucleus moving at very high speeds), beta particles (a high-speed electron or positron), gamma rays, X-rays, and galactic cosmic radiation (GCR). Examples of non-ionizing radiation include radio frequencies, microwaves, infrared, visible light and ultraviolet light. Each kind can cause damage to living and non-living objects, and could create hazards in different ways.

¹² <http://solarscience.msfc.nasa.gov/CMEs.shtml>

¹³ http://www.nasa.gov/vision/universe/solarsystem/perfect_space_storm.html

Why Is Ionizing Radiation More Dangerous than Non-Ionizing Radiation?

While non-ionizing radiation is damaging, it can easily be shielded out of an environment as is done for UV radiation. Ionizing radiation is much more difficult to avoid. Ionizing radiation has the ability to move through substances and alter them as it passes through. When this happens, it ionizes (changes the charge of) the atoms in the surrounding material with which it interacts. Ionizing radiation is like an atomic-scale cannonball that blasts through material, leaving significant damage behind. More damage can also be created by secondary particles that are knocked into motion by the primary radiation particle. The particles associated with ionizing radiation are categorized into three main groups relating to the source of the radiation: trapped radiation belt particles (Van Allen Belts), cosmic rays, and solar flare particles.¹⁴

To observe the footprints of radiation activity, have the students perform *Activity Ib, The Cloud Chamber*.

What is Galactic Cosmic Radiation?

Galactic Cosmic Radiation, or GCR, comes from outside the solar system but primarily from within our Milky Way galaxy. In general, GCR is composed of the nuclei of atoms that have had their surrounding electrons stripped away and are traveling at nearly the speed of light. Another way to think of GCR would be to imagine the nucleus of any element on the periodic table from hydrogen to uranium. Now imagine that same nucleus moving at an incredibly high speed. The high-speed nucleus you are imagining is GCR. These particles were probably accelerated within the last few million years by magnetic fields of supernova remnants (but *not* the supernova explosion itself). The giant expanding clouds of gas and magnetic fields that remain after a supernova can last for thousands of years.¹⁵ During that time, cosmic rays are probably accelerated inside them. The action of the particles bouncing back and forth in the magnetic field of the supernova remnant randomly causes some of the particles to gain energy and become cosmic rays.¹⁶ Eventually they build up enough speed that the remnant can no longer contain them and they escape into the galaxy. As they travel through the very thin gas of interstellar space, some of the GCR interacts with the gas and emits gamma rays. Detection of that reaction is how we know that GCR passes through the Milky Way and other galaxies.

The GCR permeates interplanetary space and is comprised of roughly 85% hydrogen (protons), 14% helium and about 1% high-energy and highly charged ions called HZE particles. An HZE is a heavy ion having an atomic number greater than that of helium and having high kinetic energy. Examples of HZE particles include carbon, iron, or nickel nuclei (heavy ions). Though the HZE particles are less abundant, they possess significantly higher ionizing power, greater penetration power and a greater potential for radiation-induced damage.¹⁷ GCR is extremely damaging to materials and biology. In general, we are largely shielded from GCR on Earth because of our planet's atmosphere

¹⁴ <http://see.msfc.nasa.gov/ire/iretech.htm>

¹⁵ <http://helios.gsfc.nasa.gov/gcr.html>

¹⁶ http://imagine.gsfc.nasa.gov/docs/science/know_11/cosmic_rays.html

¹⁷ http://haco.jsc.nasa.gov/projects/space_radiation.cfm

and magnetic field, whereas the Moon is not shielded from GCR because it lacks a global magnetic field and atmosphere.

In summary, GCR are heavy, high-energy ions of elements that have had all their electrons stripped away as they journeyed through the galaxy at nearly the speed of light. They can cause the ionization of atoms as they pass through matter and can pass practically unimpeded through a typical spacecraft or the skin of an astronaut. The GCR are a dominant source of radiation that must be dealt with aboard current spacecraft and

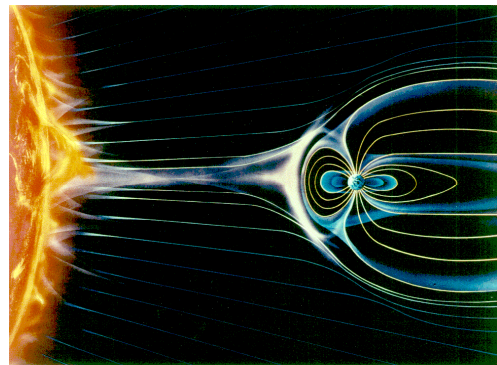


future space missions within our solar system. Because these particles are affected by the Sun's magnetic field, their average intensity is highest during the period of minimum sunspots when the Sun's magnetic field is weakest and less able to deflect them. Also, because GCR are difficult to shield against and occur on each space mission, they are often more hazardous than occasional solar particle events.¹⁸ The picture at left shows GCR falling onto the surface of Mars. GCR appear as faint white dots, whereas stars appear as white streaks.

Are We Protected from Space Radiation on Earth?

Yes, but not entirely. Life on Earth is protected from the full impact of solar and cosmic radiation by the magnetic fields that surround the Earth and by the Earth's atmosphere. The Earth also has radiation belts caused by its magnetic field. The inner radiation belt or Van Allen Belt consists of ionizing radiation in the form of very energetic protons—by-products of collisions between GCR and atoms of Earth's atmosphere. The outer radiation belts contain ions and electrons of much lower energy. As we travel farther from Earth's protective shields we are exposed to the full radiation spectrum and its damaging effects.¹⁹

In addition to a protective atmosphere, we are also lucky that Earth has a magnetic field. It shields us from the full effects of the solar wind and GCR. Without this protection, Earth's biosphere might not exist as it does today, or would be at least limited to the subsurface. The small blue torus near the Earth in the image at right²⁰ is the approximate location of the Van Allen Belts, where high-energy radiation is trapped.



¹⁸ www.spaceflight.nasa.gov/spacenews/factsheets/pdfs/radiation.pdf

¹⁹ <http://www-istp.gsfc.nasa.gov/Education/Tradbelt.html>

²⁰ http://science.msfc.nasa.gov/ssl/pad/solar/images/sunearth_lg.gif

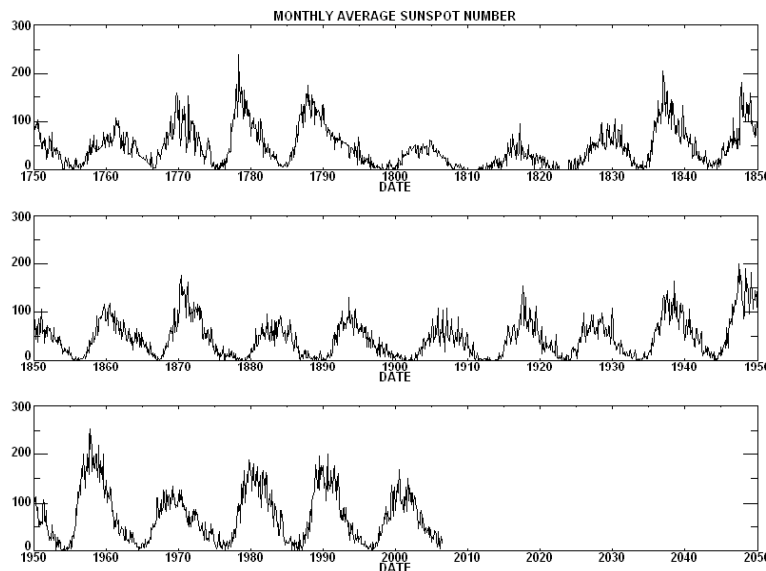
What Factors Determine the Amount of Radiation Astronauts Receive?

There are three main factors that determine the amount of radiation that astronauts receive. They include:²¹

- Altitude above the Earth – at higher altitudes the Earth's magnetic field is weaker, so there is less protection against ionizing particles, and spacecraft pass through the trapped radiation belts more often.
- Solar cycle – the Sun has an 11-year cycle, which culminates in a dramatic increase in the number and intensity of solar flares, especially during periods when there are numerous sunspots.
- Individual's susceptibility – researchers are still working to determine what makes one person more susceptible to the effects of space radiation than another person. This is an area of active investigation.

Does Space Weather Affect Astronauts?

Absolutely. Space weather is closely related to solar activity and this is important for astronauts traveling through space. Scientists have discovered that over an 11-year cycle the number of sunspots increase and decrease as shown below.²² Interestingly, the Sun is slightly brighter when there are many sunspots. During one of these periods, the Sun is more actively producing SPE and CME so the amount of radiation in the solar system is slightly increased. The number of CMEs varies with the solar cycle, going from about one per day at solar minimum, up to two or three per day at solar maximum.²³ Although scientists can predict that the Sun can produce more SPE and CME during this period, they are unable to determine specifically when SPE and CME will occur.



²¹ www.spaceflight.nasa.gov/spacenews/factsheets/pdfs/radiation.pdf

²² <http://solarscience.msfc.nasa.gov/images/zurich.gif>

²³ <http://cassfos02.ucsd.edu/public/tutorial/Sun.html>

Because the levels of protection vary, the radiation environments vary between planets and moons, even at different places on the surface of individual planets. The ISS has well-shielded areas. In addition, astronauts and the ISS itself are largely protected by the Earth's magnetic field because it is in low Earth orbit. In contrast, during a deep space journey to the Moon (200,000 miles way) or Mars (35,000,000 miles away at closest approach), astronauts and their vehicles will venture far outside of the 30,000-mile radius of the Earth's protective magnetic shield. For any future long-duration deep-space exploration, radiation levels will be so high that specially designed storm shelters will be needed to protect astronauts from receiving deadly doses of radiation during high SPE/CME periods. For safe operations on the Moon or when traveling to Mars a coordinated system of satellites will be needed to monitor space weather to help warn astronauts when it is necessary to go into their shelters.²⁴ This will be necessary because although increases and decreases in overall solar activity can be fairly well predicted over an 11-year cycle, there are unexpected short-term events like solar flares, SPE and CME that cannot be predicted, which would put a crew in great danger.

How Is Radiation Measured?

There are several properties of radiation that must be considered when measuring or quantifying radiation. These include the magnitude of radioactivity of the source, the energy of the radiation itself, the amount of radiation in the environment, and the amount of radiation energy that is absorbed. Collectively, these properties determine the nature of the radiation itself.²⁵ It is very important to understand that equal doses of different kinds of radiation are not equally as damaging. To account for the difference, radiation dose is expressed as “dose equivalent” The following chart summarizes each parameter:

Parameter	Radioactivity	Absorbed Dose	Dose Equivalent*	Exposure (for x-rays and gamma rays only)	Energy
Definition	Rate of radiation emission (transformation or disintegration) from a radioactive substance	Energy imparted by radiation per unit mass onto an absorbing material	Expression of dose in terms of its biological effect	Quantity that expresses the ability of radiation to ionize air and thereby create electric charges that can be collected and measured	The capacity to do work
Common Units Measurement Label	Curie (Ci) 1 Ci = 37 GigaBq (this is a large amount)	rad 1 rad = 100 ergs/g	rem	Roentgen (R)	Joule (J)
International System of Units (SI) Measurement Label	Becquerel (Bq) 1 Bq = 1 event of radiation emission per second (this is a very small amount)	Gray (Gy) 1 Gy = 100 rad	Sievert (Sv) 1Sv=100 rem (this is a large dose) 1 Gy air dose equivalent = 0.7 Sv 1 R ≈ 10 mSv of tissue dose	Coulomb/kilogram (C/kg) 1 R = 2.58 x 10 ⁻⁴ C/kg air	electronvolts (eV)

²⁴ <http://marsprogram.jpl.nasa.gov/spotlight/odyssey-mission-success.html>

²⁵ http://www.ccohs.ca/oshanswers/phys_agents/ionizing.html

*DE = Absorbed Dose x Quality Factor (Q), where Q depends on the type of radiation
Q = 1 for gamma, X-ray, or beta radiation; Q = 20 for alpha radiation

To get a better understanding of radiation exposure on Earth, have students fill out the *Measuring Your Radiation Worksheet*, Activity 1c. This will give them examples of radiation sources and doses.

Are there Radiation Exposure Limits?

Yes. The specific organ and career exposure limits are determined by one's age and gender. The typical average dose for a person is about 360 mrem per year, or 0.0036 Sv, which is a small dose. However, International Standards allow exposure to as much as 5000 mrem (0.05 Sv) a year for those who work with and around radioactive material. For spaceflight, the limit is higher. The NASA limit for radiation exposure in low-Earth orbit is 0.50 Sv/year, or 50 rem/year. Note that the values are lower for younger astronauts. Since it is presumed that although they may live longer than older astronauts, exposure to larger amounts radiation early in their careers could present greater health risks during old age.

Career Exposure Limits for NASA Astronauts by Age and Gender ²⁶				
Age (years)	25	35	45	55
Male	1.50 Sv	2.50 Sv	3.25 Sv	4.00 Sv
Female	1.00 Sv	1.75 Sv	2.50 Sv	3.00 Sv

The career depth equivalent dose limit is based upon a maximum 3% lifetime excess risk of cancer mortality. The total equivalent dose yielding this risk depends on gender and age at the start of radiation exposure. Assume that a younger person can be exposed to less radiation because they have more life to live, and therefore a longer chance to develop subsequent health problems. The career equivalent dose limit is approximately equal to the following formulas in Sv:²⁷

$$\text{MEN: } \frac{200 + 7.5 (\text{age} - 30)}{100}$$

$$\text{WOMEN: } \frac{200 + 7.5 (\text{age} - 38)}{100}$$

²⁶ <http://srag-nt.jsc.nasa.gov/RadDocs/TM104782/techmemo.htm>

²⁷ <http://srag-nt.jsc.nasa.gov/RadDocs/TM104782/techmemo.htm>

The following chart compares the specific exposure limits between the general public and astronauts. Astronauts who spend three months in the ISS will be subjected to over three times the maximum recommend dosage of radiation for one year.

Depth of Radiation Penetration and Exposure Limits for Astronauts and the General Public (in Sv)				
	Exposure Interval	Blood Forming Organs (5 cm depth)	Eyes (0.3 cm depth)	Skin (0.01 cm depth)
Astronauts	30 Days	0.25	1.0	1.5
	Annual	0.50	2.0	3.0
	Career	1-4	4.0	6.0
General Public	Annual	0.001	0.015	0.05

The chart below compares and contrasts various missions and their durations with the observed radiation dose:

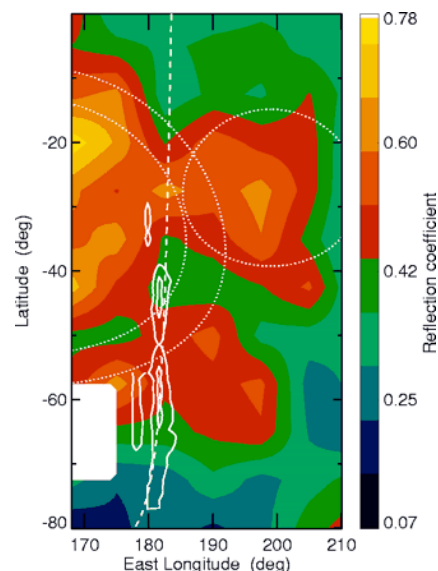
Mission Type	Radiation Dose
Space Shuttle Mission 41-C (8-day mission orbiting the Earth at 460 km)	5.59 mSv
Apollo 14 (9-day mission to the Moon)	11.4 mSv
Skylab 4 (87-day mission orbiting the Earth at 473 km)	178 mSv
ISS Mission (up to 6 months orbiting Earth at 353 km)	160 mSv
Estimated Mars mission (3 years)	1200 mSv

Crews aboard the space station receive an average of 80 mSv for a six-month stay at solar maximum (the time period with the maximum number of sunspots and a maximum solar magnetic field to deflect the particles) and an average of 160 mSv for a six-month stay at solar minimum (the period with the minimum number of sunspots and a minimum solar magnetic field). Although the type of radiation is different, 1 mSv of space radiation is approximately equivalent to receiving three chest X-rays. On Earth, we receive an average of 2 mSv every year from background radiation alone.²⁸

²⁸ www.spaceflight.nasa.gov/spacenews/factsheets/pdfs/radiation.pdf

How Does the Radiation Environment on Earth Compare to the Radiation Environment on the Moon and Mars?

NASA has collected a variety of radiation and environmental data from the Moon and Mars. During the Lunar Prospector mission, NASA scientists discovered that there are some areas of the Moon that have a weak magnetic field.²⁹ Magnetic fields have the ability to deflect small amounts of radiation. Locations with these fields are slightly more protected and might be candidate sites for bases on the Moon. Mars also has similar magnetic fields, though greater than those of the Moon. As shown in the right image, the strongest magnetic fields on the Moon are located at $\sim 20^\circ\text{S}$, 170°E and $\sim 43^\circ\text{S}$, 170°E . The Lunar Reconnaissance Orbiter will continue to measure magnetic fields on the Moon beginning in 2008.



The Moon and Mars are still extremely vulnerable to the effects of space radiation in spite of localized magnetic fields. They do not have global magnetic fields like those of Earth. As a result, their surfaces are not shielded from SPE that erupt from the surface of the Sun. In addition, the GCR that permeates interstellar space can freely bombard the surface of the Moon and Mars.

Finally, the Moon and Mars do not have dense atmospheres. Although Mars has an extremely thin atmosphere composed primarily of carbon dioxide, it is not thick enough to shield it from most cosmic radiation. The Moon essentially lacks an atmosphere altogether.

In order to minimize radiation exposure, people living on the Moon or Mars will need to limit the time they spend outside in their spacesuits and the distance they travel from their protective habitats. The total amount of radiation that astronauts receive will depend greatly upon solar activity, their location with respect to planetary magnetic fields, and the amount and type of radiation shielding used in habitats and spacecraft. Radiation exposure for astronauts aboard the ISS in Earth orbit is typically equivalent to an annualized rate of 20 to 40 rems (0.2 – 0.4 Sv).³⁰ The average dose-equivalent rate observed on a previous Space Shuttle mission was 3.9 micro Sv/hour, with the highest rate at 96 micro Sv/hour, which appeared to have occurred while the Shuttle was in the South Atlantic Anomaly region of Earth's magnetic field (1 Sv = 1,000 milli Sv = 1,000,000 micro Sv).³¹

For a six-month journey to Mars an astronaut would be exposed to roughly 0.3 Sv, or a total of 0.6 Sv for the round-trip. If we assume that the crew would spend 18 months on the surface while they wait for the planets to realign to make the journey back to Earth

²⁹ <http://www.sciencemag.org/cgi/content/full/281/5382/1480>

²⁷ http://haco.jsc.nasa.gov/projects/space_radiation.cfm

³¹ http://exploration.nasa.gov/programs/station/BBND_lite.html

possible, they will be exposed to an additional 0.4 Sv, for a grand total exposure of about 1 Sv. Note that an astronaut repeating the same journey on multiple occasions could receive less or more radiation each time, depending if they are in the line of a CME or SPE.

Identifying and mitigating the effects of radiation on astronauts are critical goals of NASA scientists. We will discuss the biological effects of radiation in Module 2 and countermeasures in Module 3.

.....

Suggested Activity 1a: Modeling Waves in the Electromagnetic Spectrum

.....

In this activity you will use a spring-coiled toy to model electromagnetic radiation and measure the properties of the wave you create.

Objectives:

- Model waves in the electromagnetic spectrum.
- Classify types of electromagnetic energy by wavelength.
- Demonstrate the relationship between wavelength, frequency, and energy.

Research Question:

What kind of radiation strikes the surface of the Moon? How is it different from what is found on the surface of the Earth?

Discussion Questions:

- What happens to wavelength if you increase the frequency of the waves?
- How does the amount of energy in continuously generated high-frequency waves compare to low-frequency waves?

Materials

A metal spring-coiled toy, meter stick, stopwatch

Directions:

1. Stretch a spring-coiled toy out over several meters between two people on a smooth, open floor.
2. Wave one end of the spring-coiled toy side to side to produce transverse waves that ripple toward the other person. Note: if the spring-coiled toy is stretched very tight, the wave will reflect back to the source and will alter the speed of the wave; make sure you are producing waves that are uniform and alike
3. Measure and record the amount of time it takes one wave to travel from one person to the next and the distance between the two people. Use this information to calculate frequency in waves per second and the velocity of the wave. Use the diagram and formulas to help in your calculations.
4. Calculate wavelength and energy. After completing this for a wave of one frequency, alter the wavelength or frequency and make more calculations to observe how waves of different wavelengths or frequencies behave. Use the diagram and formulas to help in your calculations.

For electromagnetic waves:

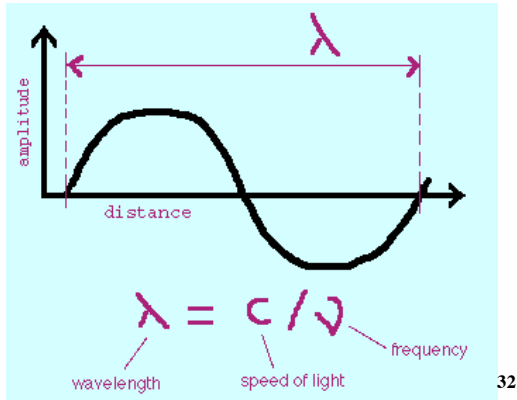
$$\lambda = c / \nu$$

Wavelength (λ) [pronounced lambda] equals the speed of light (c) divided by the frequency (ν) [pronounced nu]

$$E = h \times \nu$$

Energy equals Planck's constant* (h) times the frequency

*Approximately 6.625×10^{-27}



For the waves generated with the spring-coiled toy:

$$V = \lambda \times f$$

Speed of the wave equals wavelength times the frequency of the wave

³² http://imagine.gsfc.nasa.gov/docs/science/known_12/emspectrum.html

.....

Suggested Activity 1b: The Cloud Chamber

.....

In this activity³³ you will use a device called a cloud chamber to observe the footprints of radiation in a dense gas.

Objectives:

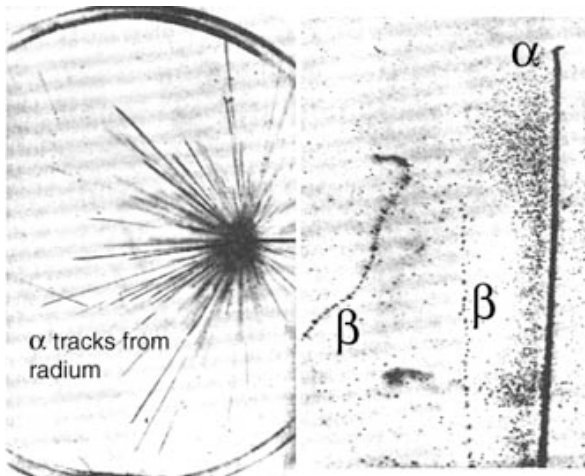
- Define and identify common examples of radiation.
- Distinguish between non-ionizing and ionizing radiation.
- Describe the differences between alpha (α), beta (β), and gamma (γ) particles.
- Determine what methods of protection are necessary for each type of radiation.

Research Question:

It is January 16, 2023; your team continues to develop recommendations for materials to be used for spacesuits and habitation units on the Moon. How much protection do we need from alpha, beta and gamma radiation on Earth? On the Moon? In space?

Discussion Questions:

- Do you see radiation in the cloud chamber? Why or why not?
- What is happening to the radioactive source?
- How do things become less radioactive as time passes?



An alpha particle left a broad, straight path of definite length while an electron produced a light path with bends due to collisions. Gamma rays did not produce a visible track since they produce very few ions in air.

³³ http://www.nrc.gov/reading-rm/basic-ref/teachers/unit1.html#activity_1

Materials:

- small transparent container with transparent lid
- flat black spray paint
- blotter paper
- pure ethyl alcohol
- radioactive source
- masking tape
- dry ice and gloves or tongs for handling
- Styrofoam square
- flashlight

Directions:

1. Paint the bottom of the container with black paint and let it dry. Cut the blotter paper into a strip about as wide as the height of the container. Cut two windows in the strip, as shown, and place it against the inside of the container.
2. Pour enough ethyl alcohol into the cloud chamber to cover the bottom of the container. The blotter paper will absorb most of it.
3. Place the radioactive source in the cloud chamber and seal the lid with tape.



Caution: Dry ice should be handled very carefully! It can burn unprotected skin.

4. Place the cloud chamber on the dry ice to super-chill it. Wait about five minutes. Darken the room. Shine the flashlight through the windows of the chamber while looking through the lid. You should see "puffs" and "trails" coming from the source. These are the "footprints" of radiation as it travels through the alcohol vapor. The vapor condenses as the radiation passes through. This is much like the vapor trail left by high-flying jets.

Each kind of particle will have a unique footprint:

- Alpha: sharp tracks about 1 cm long
- Beta: thin tracks 3 cm to 10 cm long
- Gamma: faint, twisting and spiraling tracks

(**Note:** Equipment and materials for this activity are commercially available from various educational resources.)

References:

http://www.nrc.gov/reading-rm/basic-ref/teachers/unit1.html#activity_1

.....

Suggested Activity 1c: Radiation Exposure on Earth

.....

In this activity you will use the following worksheets to determine your average annual radiation dose here on Earth.

Objectives:

- Explain the differences between geomagnetically trapped particles, galactic cosmic rays and solar particle events.
- Discuss the protection offered by Earth's atmosphere.
- Describe why a space weather forecast is important for people on Earth and in space.
- Determine your average annual radiation dose here on Earth.

Research Question:

It is February 22, 2023 and you are deciding the best launch dates for the voyage to the Moon. Your recommendation is needed for the best timeframe to travel to avoid peak solar activity. Use the space weather forecast data to determine several options.

Discussion Questions:

- What are some good examples of each source of cosmic radiation?
- How could you model the Earth's atmosphere to demonstrate its layers and thin nature?
- How have humans affected the atmosphere's ability to protect us from radiation?
- What spacecraft are important in forecasting of space weather?
- How can you reduce the amount of radiation you are exposed to?

Materials:

Measuring Your Annual Radiation Dose worksheet

References:

The primary source for this information is the Environmental Protection Agency and the American Nuclear Society's brochure *Personal Radiation Dose*.

The United States Nuclear Regulatory Commission
<http://www.nrc.gov/what-we-do/radiation/affect.html>

The Environmental Protection Agency
<http://epa.gov>

Directions: Place the value from the middle column that corresponds to your situation in the right column (Your Annual Dose). All values on this page are in milliSieverts (mSv). Add all of the numbers in the right column to determine your estimated annual radiation dose.

Factors	Common Sources of Radiation	Annual Dose																						
Where you live	Cosmic Radiation (from outer space) Exposure depends on your elevation (how much atmosphere is above you to block radiation).	_____ mSv																						
	<table border="1"> <thead> <tr> <th>Elevation (average cities' data from the United States Geological Survey website: http://www.usgs.gov)</th><th>Value (mSv)</th></tr> </thead> <tbody> <tr> <td>Sea level (New York, Philadelphia, Houston, Baltimore, Boston, New Orleans, Jacksonville, Seattle)</td><td>0.26</td></tr> <tr> <td>1-1000 feet (Chicago, Detroit, San Diego, Dallas, Minneapolis, St. Louis, Indianapolis, San Francisco, Memphis, Washington, DC, Milwaukee, Cleveland, Columbus, Atlanta)</td><td>0.28</td></tr> <tr> <td>1001-2000 feet (Phoenix, Pittsburgh, San Jose, Oklahoma City)</td><td>0.31</td></tr> <tr> <td>2001-3000 feet (Las Vegas, Los Angeles, Honolulu, Tucson)</td><td>0.35</td></tr> <tr> <td>3001-4000 feet (El Paso)</td><td>0.41</td></tr> <tr> <td>4001-5000 feet (Salt Lake City)</td><td>0.47</td></tr> <tr> <td>5001-6000 feet (Denver, Albuquerque)</td><td>0.52</td></tr> <tr> <td>6001-7000 feet</td><td>0.66</td></tr> <tr> <td>7001-8000 feet</td><td>0.79</td></tr> <tr> <td>8001-9000 feet</td><td>0.96</td></tr> </tbody> </table>	Elevation (average cities' data from the United States Geological Survey website: http://www.usgs.gov)	Value (mSv)	Sea level (New York, Philadelphia, Houston, Baltimore, Boston, New Orleans, Jacksonville, Seattle)	0.26	1-1000 feet (Chicago, Detroit, San Diego, Dallas, Minneapolis, St. Louis, Indianapolis, San Francisco, Memphis, Washington, DC, Milwaukee, Cleveland, Columbus, Atlanta)	0.28	1001-2000 feet (Phoenix, Pittsburgh, San Jose, Oklahoma City)	0.31	2001-3000 feet (Las Vegas, Los Angeles, Honolulu, Tucson)	0.35	3001-4000 feet (El Paso)	0.41	4001-5000 feet (Salt Lake City)	0.47	5001-6000 feet (Denver, Albuquerque)	0.52	6001-7000 feet	0.66	7001-8000 feet	0.79	8001-9000 feet	0.96	
	Elevation (average cities' data from the United States Geological Survey website: http://www.usgs.gov)	Value (mSv)																						
	Sea level (New York, Philadelphia, Houston, Baltimore, Boston, New Orleans, Jacksonville, Seattle)	0.26																						
	1-1000 feet (Chicago, Detroit, San Diego, Dallas, Minneapolis, St. Louis, Indianapolis, San Francisco, Memphis, Washington, DC, Milwaukee, Cleveland, Columbus, Atlanta)	0.28																						
	1001-2000 feet (Phoenix, Pittsburgh, San Jose, Oklahoma City)	0.31																						
	2001-3000 feet (Las Vegas, Los Angeles, Honolulu, Tucson)	0.35																						
	3001-4000 feet (El Paso)	0.41																						
	4001-5000 feet (Salt Lake City)	0.47																						
	5001-6000 feet (Denver, Albuquerque)	0.52																						
	6001-7000 feet	0.66																						
	7001-8000 feet	0.79																						
	8001-9000 feet	0.96																						
	Terrestrial Radiation (from the ground) <ul style="list-style-type: none"> If you live in a state that borders the Gulf of Mexico or Atlantic Ocean, add 0.16 mSv. If you live in the Colorado Plateau area (around Denver), add 0.63 mSv. If you live anywhere else in the continental U.S., add 0.30 mSv. 	_____ mSv																						
House Construction <ul style="list-style-type: none"> If you live in a stone, adobe, brick, or concrete building, add 0.07 mSv. 	_____ mSv																							
Power Plants <ul style="list-style-type: none"> If you live within 50 miles of a nuclear power plant, add 0.0001 mSv. (For locations of nuclear power plants, visit the United States Nuclear Regulatory Commission website: http://www.nrc.gov/info-finder/reactor) If you live within 50 miles of a coal-fired power plant, add 0.0003 mSv. 	_____ mSv																							
Food																								
Water																								
Air																								
	Internal Radiation (average values) <ul style="list-style-type: none"> From food (Carbon-14 and Potassium-40) and from water (radon dissolved in water) From air (radon) 	_____ mSv <u>0.40</u> mSv <u>2.00</u> mSv																						
Total (page 1)	Add all the values for your annual radiation dose in the third column. Copy this number to the top line on the reverse side of this sheet.	_____ mSv																						
Total (page 1)	Transfer the total from the reverse side onto this line.	_____ mSv																						

Factors	Common Sources of Radiation		Annual Dose
How You Live	Weapons test fallout	.01 mSv	_____ mSv
	Jet plane travel	0.005 mSv per hour in the air	_____ mSv
	If you have porcelain crowns or false teeth	0.0007 mSv per tooth/crown	_____ mSv
	If you wear a luminous wrist-watch	0.0006 mSv	_____ mSv
	If you watch TV	0.01 mSv	_____ mSv
	If you use a computer screen	0.01 mSv	_____ mSv
	If you have a smoke detector	0.00008 mSv	_____ mSv
	If you use a gas camping lantern	0.002 mSv	_____ mSv
	If you wear a plutonium-powered pacemaker	1.00 mSv	_____ mSv
	If you smoke	160.0 mSv	_____ mSv
Medical Tests	Medical Diagnostic Tests (per procedure)		
	Extremity x-ray (arm, hand, foot, or leg)	0.01 mSv	_____ mSv
	Dental x-ray	0.01 mSv	_____ mSv
	Chest x-ray	0.06 mSv	_____ mSv
	Pelvis/hip x-ray	0.65 mSv	_____ mSv
	Skull/neck x-ray	0.20 mSv	_____ mSv
	Barium enema	4.05 mSv	_____ mSv
	Upper GI x-ray	2.45 mSv	_____ mSv
	CAT Scan (head and body)	1.1 mSv	_____ mSv
	Nuclear Medicine (e.g. thyroid scan)	0.14 mSv	_____ mSv
Total	Add up all of the numbers in the third column to determine your annual radiation dose on Earth.		_____ mSv

Appendix 1: Additional Websites

Introduction:

Brookhaven National Laboratory

<http://www.bnl.gov/world/>

The Scenario:

Space Habitat

<http://www.spacefuture.com/habitat/habitat.shtml>

Wikipedia

http://en.wikipedia.org/wiki/Space_colonization

Module 1: Radiation:

Apollo: The Apollo Program

<http://www.nasm.si.edu/collections/imagery/apollo/apollo.htm>

Environmental Protection Agency

<http://www.epa.gov/radiation/students/types.html>

Jet Propulsion Laboratory: 2001 Mars Odyssey

<http://mars.jpl.nasa.gov/odyssey/>

Cambridge Physics—Cloud Chamber Animations

http://www-outreach.phy.cam.ac.uk/camphy/cloudchamber/cloudchamber8_1.htm

Space Environment Center Space Weather

<http://www.sec.noaa.gov/wwire.html>

Space Weather.com

<http://spaceweather.com/>

The Center for Science Education

<http://cse.ssl.berkeley.edu/>

Appendix 1: National Education Standards³⁴ by Module

Module 1 Radiation

Unifying Concepts and Processes

Systems, order and organization

Science in personal and Social Perspectives

Natural and human-induced hazards

Physical Science

Conservation of energy and increase in disorder

Structure of atoms

Earth and Space Science

Energy in the Earth System

³⁴ <http://lab.nap.edu/html/nses/6a.html>

National Aeronautics and Space Administration

Ames Research Center
Moffett Field, CA 94035-1000

www.nasa.gov